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COMPARATIVE STUDY FOR MITIGATING THE SOFT STOREY EFFECT IN MULTI STOREY BUILDINGS USING DIFFERENT STRUCTURAL ARRANGEMENTS

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ABSTRACT

This paper focuses on studying the effects of soft storey configuration in the buildings and remedying it by using different structural arrangements, such as shear walls, diagonal steel bracing and cross steel bracings. The linear dynamic analysis (response spectrum analysis) has been adopted for various symmetrical buildings such as low rise (G+6), medium rise (G+14) and high rise (G+24). The responses of the models, in terms of storey drift, lateral displacement, storey shear, storey stiffness and bending moment variation are compared for different configurations and presented. It can be effectively concluded that the provision of shear walls can reduce the effects of soft storey to a much greater extend. Cross steel bracings also play an inevitable role in reducing the soft storey effect in the buildings. As the height of the building increases, the factors evaluated in this paper exert a major impact on the building's stability, thus necessitating the need for in depth study in this area.

Key words: Soft storey, Structural arrangements, Linear response spectrum analysis, Shear Walls, Bracings.

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1. INTRODUCTION

Over the past few years, parking has become an inevitable problem in metro cities. One of the many solutions to this problem is to provide open ground storey configuration to the building. Although this serves the purpose of parking space, but it reduces the storey stiffness thus

form it a soft storey. Constructing soft storey is a modern multistoried construction philosophy adopted commonly these days. A soft storey is also termed as a weak storey or a stilt storey or open ground storey. According to IS:1893-2002 (Part-1), a soft storey is labeled as the one for which the lateral stiffness is less than 70% of that in the storey above it or 80% of the average stiffness of three stories above it [1].

The buildings with open ground storey configurations have shown higher tendency for collapse during earthquakes due to the soft storey effect. This effect is mainly due to increased flexibility of soft storeys as compared to normal floors. The stiffness of the building will be reduced due to the presence of open ground storey configuration and because of this, large bending moments and shear forces act at that storey. Now-a-days this type of open ground storey configuration is being preferred to tackle the problem of parking space [2]–[5]. Here, the non-structural components such as brick masonry are attached to column of the upper floor and bottom storey is left devoid of infill walls. In such buildings, major percentage of the base shear is required to be resisted by the beam-column joints of the ground storey. This leads to eventual collapse of the building. So it is very important to mitigate the effect of soft storey in buildings to a greater extend. In order to achieve this, various structural arrangements can be provided in the buildings [3], [6]–[13]. The most commonly adopted methods are: (i) providing infill walls, (ii) providing shear walls, (iii) providing steel bracings, (iv) providing cross steel bracings, and (v) using stiffer columns. In the present study, hypothetical RCC buildings of varying heights such as low rise (G+6), medium rise (G+14) and high rise (G+24) are considered and the following five structural arrangements are incorporated in them:

- Bare frame building
- Frame with open ground storey and infill walls in the upper storey of the building.
- Frame with open ground storey and infill walls in the upper storey with provision of shear wall at corners.
- Frame with open ground storey with provision of steel diagonal bracing at ground storey and infill walls in the upper storey of the building.
- Frame with open ground storey with provision of steel cross bracing at ground storey and infill walls in the upper storey of the building.

The performance of the building is evaluated in terms of lateral displacement, storey drift, storey stiffness, storey shear & bending moment variation, and the results for different structural arrangements are compared for low rises, medium rises and high rises. The generated models are given following denotations:

Table 1 Model Denotation

Model Description	Denotation
High rise building - Bare Frame	HR-A
High rise building - Open ground storey with infills in upper storey	HR-B
High rise building - Open ground storey, infills in upper storey and provision of shear walls at corner locations	HR-C
High rise building - Open ground storey, infills in upper storey and provision of diagonal steel bracings at ground storey	HR-D
High rise building - Open ground storey, infills in upper storey and provision of steel cross bracings at ground storey	HR-E
Medium rise building - Bare Frame	MR-A
Medium rise building - Open ground storey with infills in upper storey	MR-B
Medium rise building - Open ground storey, infills in upper storey and provision of	MR-C

shear walls at corner locations	
Medium rise building - Open ground storey, infills in upper storey and provision of diagonal steel bracings at ground storey	MR-D
Medium rise building - Open ground storey, infills in upper storey and provision of steel cross bracings at ground storey	MR-E
Model Description	**Denotation**
Low rise building - Bare Frame	LR-A
Low rise building - Open ground storey with infills in upper storey	LR-B
Low rise building - Open ground storey, infills in upper storey and provision of shear walls at corner locations	LR-C
Low rise building - Open ground storey, infills in upper storey and provision of diagonal steel bracings at ground storey	LR-D
Low rise building - Open ground storey, infills in upper storey and provision of steel cross bracings at ground storey	LR-E

2. MODELLING & ANALYSIS

Hypothetical buildings of G+6 (low rise), G+14 (medium rise) and G+24 (high rise) are assumed for seismic analysis. The building is symmetric and regular in plan. For modelling the structure, line elements are used for beams and columns and concrete elements were used for slabs. All the degree of freedom is restrained by making the base of the structure rigid. The buildings are located in seismic zone III according to IS:1893-2002 (Part-1) and is founded on soil type II (medium soil).

Table 2 Building Description

S.No.	Description	Specifications
1.	Building Frame System	OMRF
2.	Ground Storey height	3.5m
3.	Typical Storey height	3.5m
4.	Type of soil	Medium (II)
5.	Support Condition	Fixed
6.	Grade of concrete	M30
7.	Grade of steel	Fe 415
8.	Live Load	3.5 kN/m^2
9.	Floor Finish	1 kN/m^2
10.	Steel section	ISMB 350
11.	Infill Panel	Brick Masonry
12.	Importance factor	1
13.	Response Reduction Factor	3
14.	Column Size	400mm x 400mm
15.	Beam size	300mm x 300mm
16.	Slab Thickness	125mm
17.	Thickness of brick wall	230mm

The modelling of masonry infill wall in the building is done by equivalent diagonal strut method as given in FEMA-273. The thickness and material properties of diagonal strut are similar to that of infill wall. According to FEMA-273, width of diagonal strut is given by,

$$a = 0.175\ (\lambda_1 h_{col})^{-0.4}\ r_{inf} \qquad (1)$$

where,

$$\lambda_1 = \left[\frac{E_{me}\, t_{inf} \sin 2\theta}{4\, E_{fe}\, I_{col}\, h_{inf}}\right]^{1/4} \tag{2}$$

and,

h_{col} = Column height between center lines of beams (in.),

h_{inf} = Height of infill panes (in.),

E_{fe} = Expected Modulus of Elasticity of Frame material (psi),

E_{me}= Expected Modulus of Elasticity of Infill material (psi),

I_{col} = Moment of inertia of column (in.^{4}),

L_{inf} = Length of infill panel (in.),

r_{inf} = Diagonal length of infill panel (in.),

t_{inf} = Thickness of infill panel and equivalent strut (in.),

θ = Angle whose tangent is the infill height to length aspect ratio (rad),

& λ_1 = Coefficient used to determine the equivalent width of infill strut

The generated models of Low rise buildings in ETABS, with different suggested structural arrangements are shown below in Fig. 1 (a) - (e). The models of medium rises and high rises are also provided with the same structural configurations but they are not shown here for brevity.

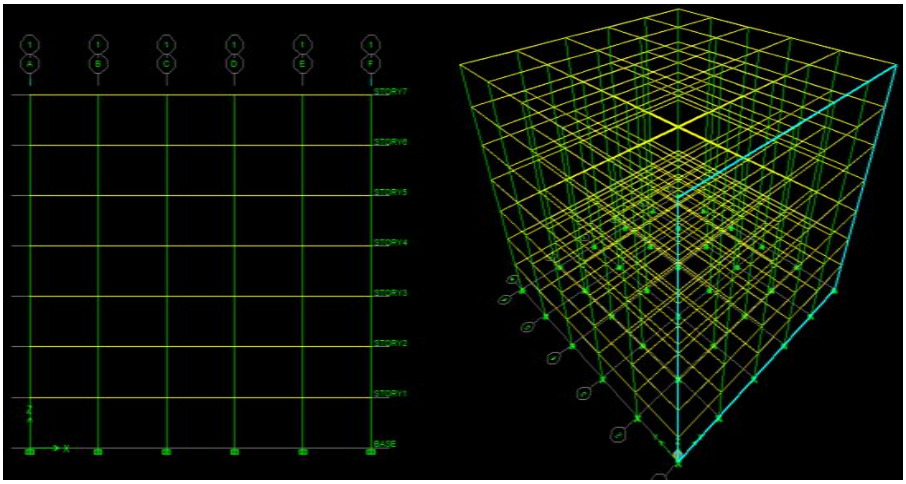


Figure 1 (a) Models of Low rise building with Bare frame configuration

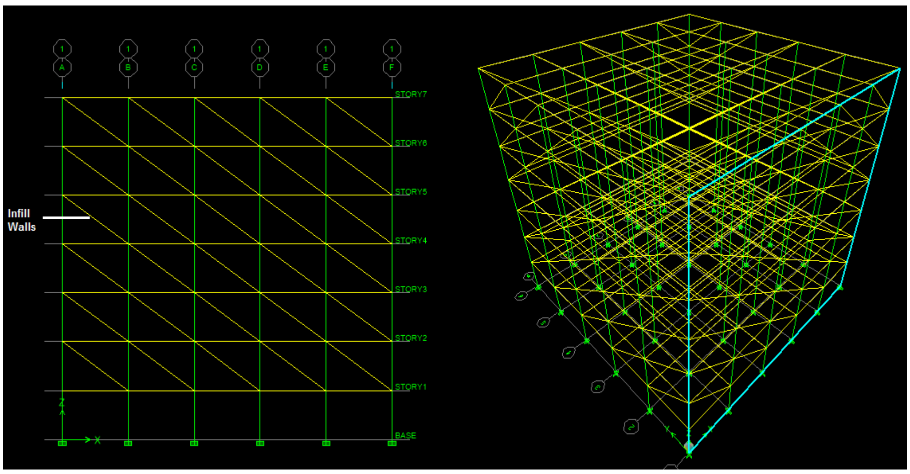
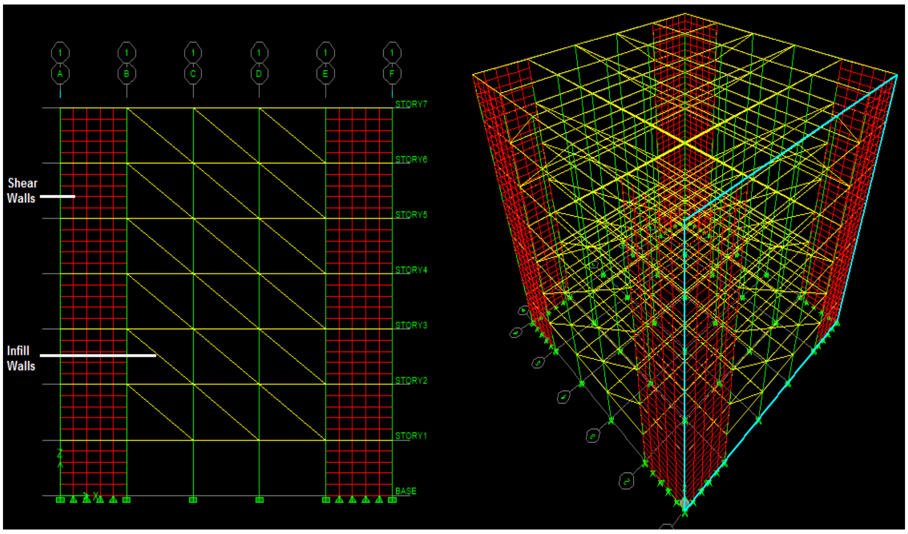


Figure 1 (b) Models of Low rise building with Soft storey configuration



Figue 1 (c) Models of Low rise building with Shear wall configuration

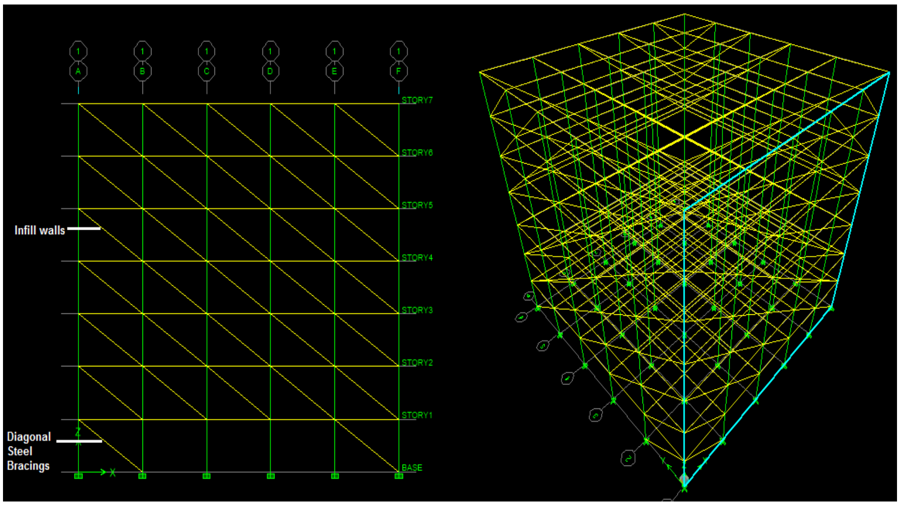


Figure 1 (d) Models of Low rise building with Diagonal steel bracings

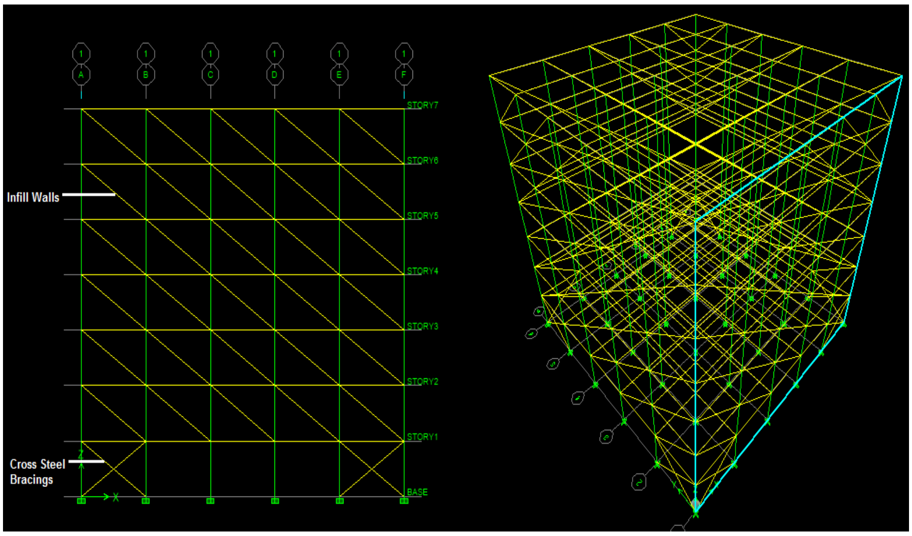


Figure 1 (e) Models of Low rise building with Cross steel bracings

In the present study, the analysis of infill frame is done by Equivalent Diagonal Strut Method. All the models are analyzed separately through Response Spectrum Analysis (RSA) by using the software ETABS. In this method, the response of a structure during an earthquake is obtained directly from the earthquake response spectrum. This procedure is quite accurate for structural design applications in which it gives an approximate peak response. This method takes into account the multiple modes of response of a building. Based on the model frequency and modal mass for each mode, a response is read from the design spectrum. Response spectrum method is performed using the design spectrum specified or by a site-specific design spectrum, which is specifically prepared for a structure at a particular project site.

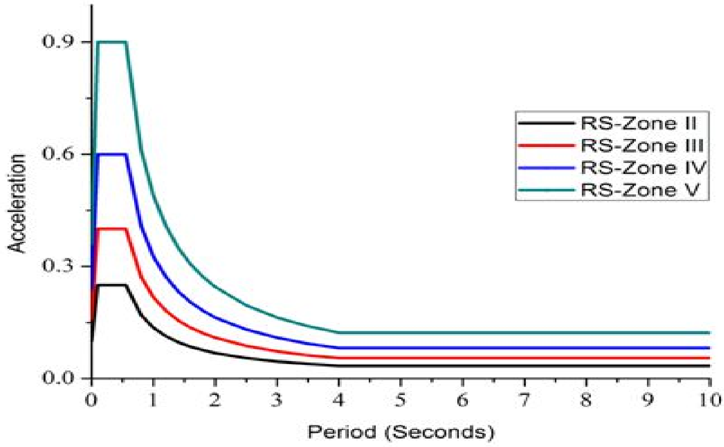
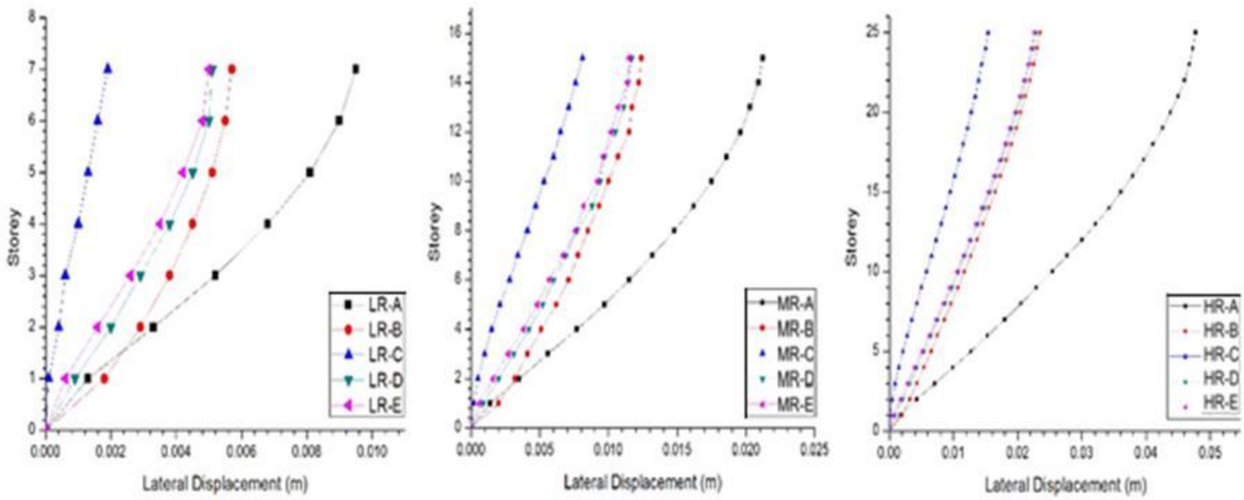


Figure 2 Response Spectra for different Seismic Zones as per IS:1893(Part-1)-2002 [1]

3. RESULTS AND DISCUSSIONS

The structure models have been analyzed and the following result has been obtained. The results of different models are compared accordingly.

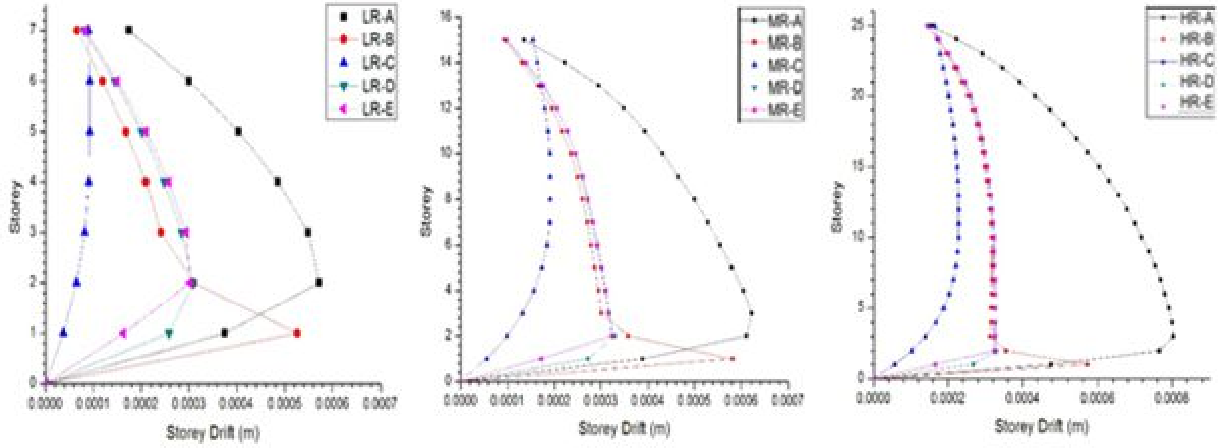


(a) (b) (c)

Figure 3 Observed values of Storey Displacement for: **(a)** Low rise, **(b)** Medium rise, & **(c)** High rise

As the height of the building increases the lateral displacement also increases, i.e. it varies along the height. In open ground storied building since there is no infill wall at the bottom storey, there will be large displacement occurring at the bottom part. From Fig. 3, it can be

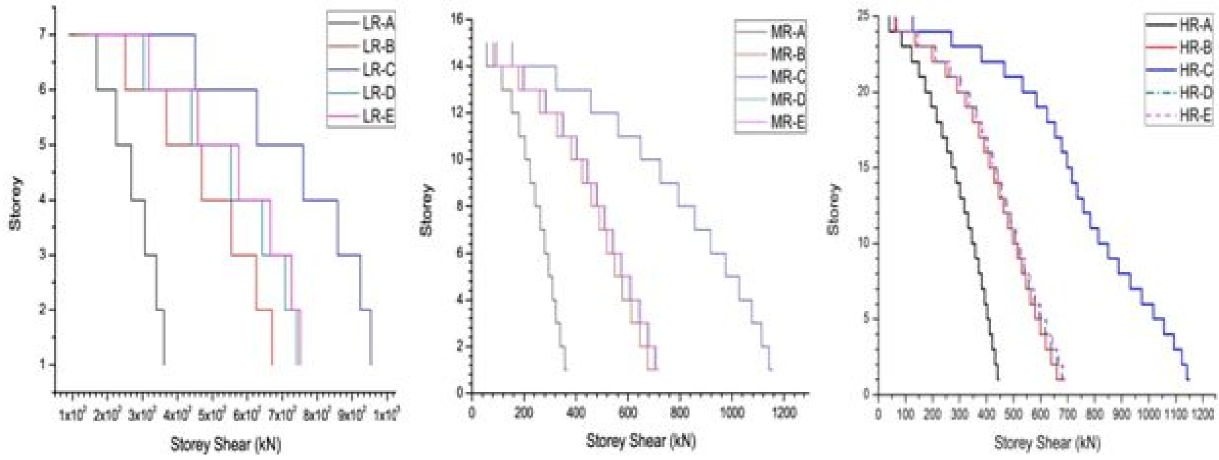
seen that there is large displacement occurring at the bottom storey of the building. But by the provision shear wall the overall displacement of the building can be reduced to much extent. Cross steel bracings also reduce the displacement to certain extent.



(a) (b) (c)

Figure 4 Observed values of Storey Drift for: **(a)** Low rise, **(b)** Medium rise, & **(c)** High rise

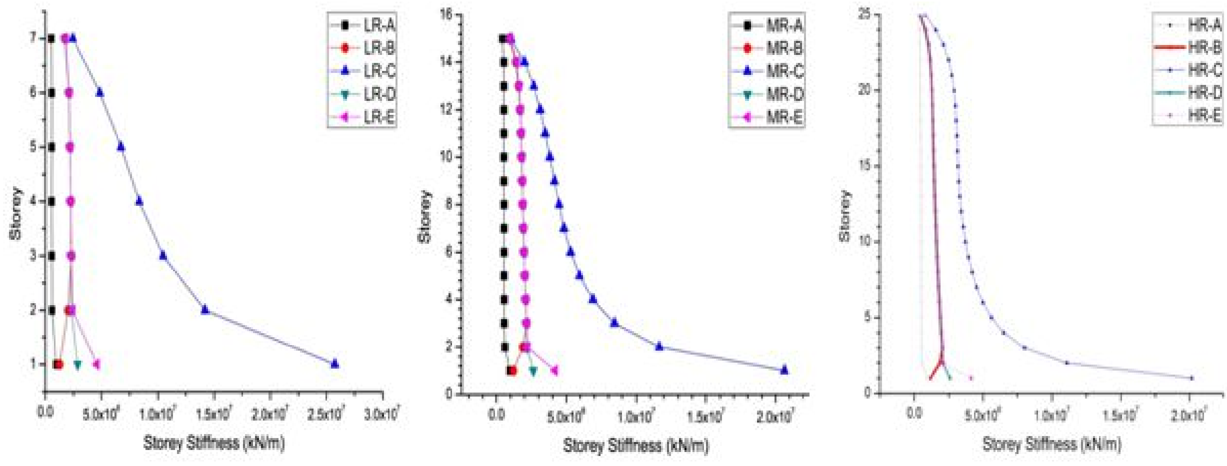
From Fig. 4, it can be pointed out that the maximum storey drift is occurring in the case of open ground storey building. As the height of the building increases, the storey drift is considerably reducing, i.e. there is a larger drift at bottom storey as compared to other storey of the open ground storey building. It can be seen that the addition of shear wall greatly reduces the ground storey drift. As compared to the provision of diagonal steel bracing, the cross-steel bracing reduces the storey drift to a greater extent.



(a) (b) (c)

Figure 5 Observed values of Storey Shear for: **(a)** Low rise, **(b)** Medium rise, & **(c)** High rise

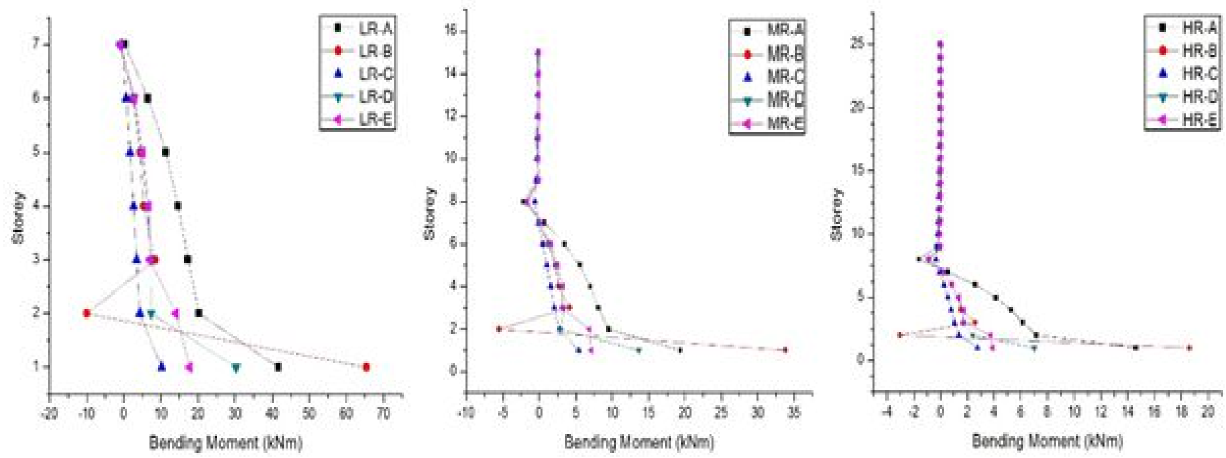
As the height of the building increases, the storey shear gets reduced. The maximum storey shear occurred at the bottom storey of the buildings. By the provision of different structural arrangements in the building, the storey shear is increased for which the buildings need to be redesigned. From Fig. 5, it can be stated that shear wall configuration can resist larger lateral force which means that it can take larger force at bottom storey.



(a) (b) (c)

Figure 6 Observed values of Storey Stiffness for: **(a)** Low rise, **(b)** Medium rise, & **(c)** High rise

Storey Stiffness is one of the most inevitable criteria taken into consideration for different type of buildings (low, medium and high rise). Storey stiffness governs the stability of the structure. The open ground storey structure will show a very low structural stability. As height of the building increases, the stiffness get reduced. By provision of shear wall there is a great increase in stiffness which adds structural stability to the buildings. Compared to the diagonal steel bracing, cross steel bracings can increase the stiffness of the building to a greater extent.

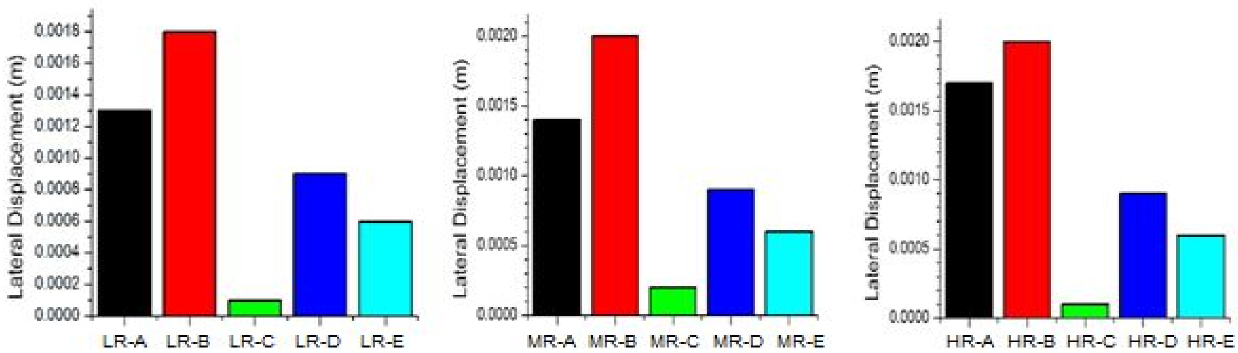


(a) (b) (c)

Figure 7 Observed values of Bending Moment for: **(a)** Low rise, **(b)** Medium rise, & **(c)** High rise

Bending moment is another important factor that governs the stability of the building. Since there is no infill wall present in the ground storey of the building, the bending moment concentration at that storey is very high. By the shear wall provision, we can reduce the bending moment concentration to certain extent. There is a reduction in bending moment as the height of the building increase. The cross-steel bracing has also reduced the bending moment to some extent as compared to open ground storey.

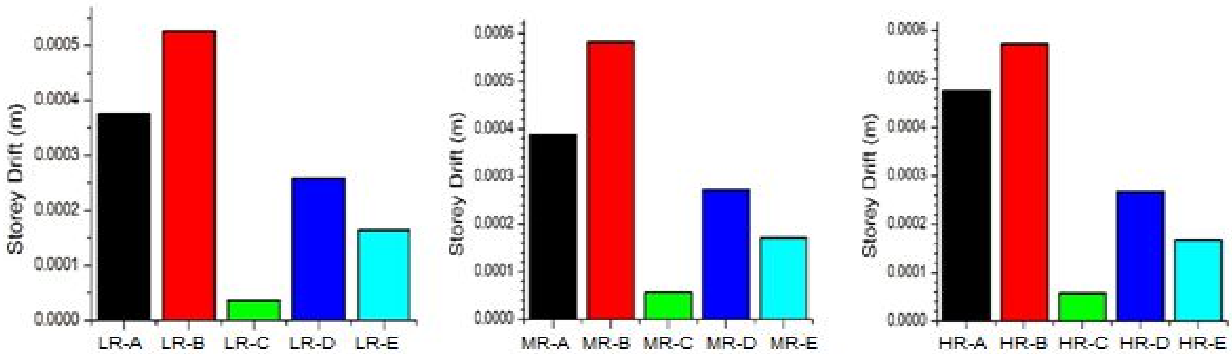
The variation in the lateral displacement, storey drift, storey shear, storey stiffness and bending moment of the open ground floor (1st storey) for each of the models with different structural arrangements are shown below in Fig. 8 - 12.



(a) (b) (c)

Figure 8 Variation of lateral displacements in 1st storey for: **(a)** Low rise, **(b)** Medium rise, **(c)** High rise

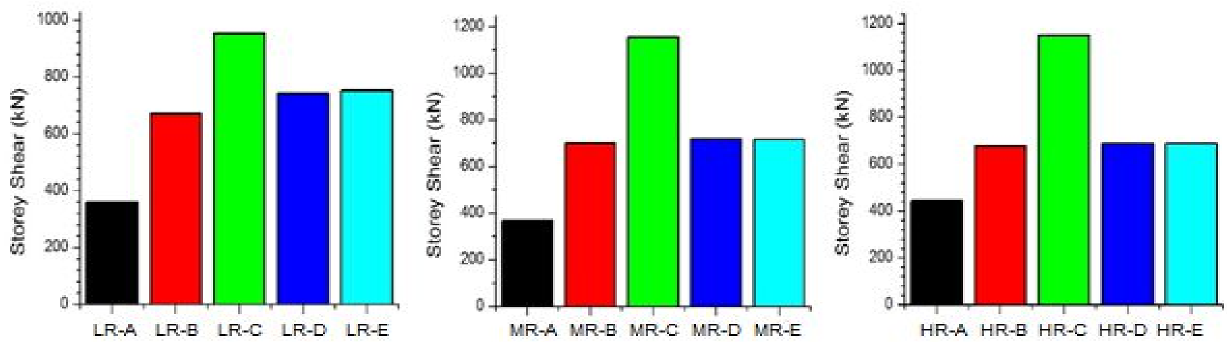
It is apparent from Fig. 8 that the provision of shear wall seems to be the most effective technique for reducing the lateral displacements. A reduction of 94.4% in case of low rise, 90% in medium rise and 95% in high rise buildings (as compared to open ground storey building with infill walls in the upper storey) can be observed by implementing shear wall configuration. The next best structural configuration seems to be cross steel bracings.



(a) (b) (c)

Figure 9 Variation of storey drifts in 1st storey for: **(a)** Low rise, **(b)** Medium rise, **(c)** High rise

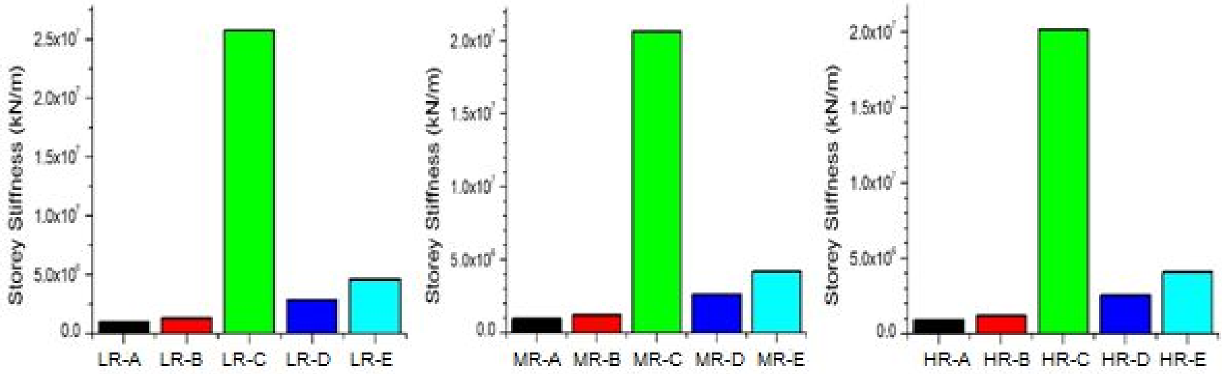
The storey drifts, as shown in Fig. 9, are minimum in case of shear wall configuration. In case of model 3, a reduction of 93% in case of low rises, 90.4% in case of medium rises and 90% in case of high rises in the values of storey drift (as compared to open ground storey configuration) can be seen. Cross steel bracings have also shown potential by reducing the storey drifts by almost 70%.



(a) (b) (c)

Figure 10 Variation of storey shear in 1st storey for: **(a)** Low rise, **(b)** Medium rise, **(c)** High rise

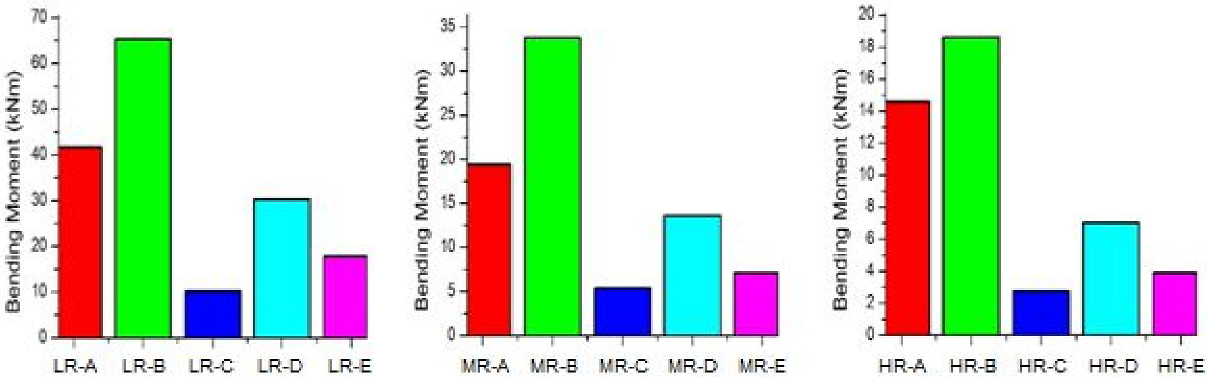
From Fig. 10, it is apparent that Model 3 i.e. building with shear wall configuration attract larger storey forces. An increase of 42% in case of low rises, 65.3% in case of medium rises and 70.4% in case of high rises with comparison to Model 2 i.e. building with open ground storey with infill wall at upper storey configuration is observed. In case of medium rises and high rises, the buildings with diagonal steel bracings and cross steel bracings attract almost similar amount of storey forces as that of open ground storey buildings.



(a) (b) (c)

Figure 11 Variation of storey stiffness in 1st storey for: **(a)** Low rise, **(b)** Medium rise, **(c)** High rise

From Fig. 11, it is apparent that the values of storey stiffness for Model 3 are extremely high in all the cases. This results in a very stiff structure. The values of stiffness for Model 3 when compared to Model 2 are 19.2 times in case of low rises, 16.2 times in case of medium rises and 16.1 times in case of high rises.



(a) (b) (c)

Figure 12 Variation of bending moments in 1st storey for: **(a)** Low rise, **(b)** Medium rise, **(c)** High rise

Fig. 12 clearly shows that for all the cases, the moment is extremely high for Model 2 i.e. for buildings with open ground storey configuration. By the provision of shear wall configuration, a reduction of 84.5% in case of low rises, 84% in case of medium rises and 85.2% in case of high rises can be achieved.

4. CONCLUSION

The effects of soft storey configuration in the buildings are studied and focus is given on the various structural arrangements to remedy it, such as shear walls, diagonal steel bracing and cross steel bracings. The performance of the building is evaluated in terms of lateral displacement, storey drift, storey shear, storey stiffness & bending moment variation. The results for different structural arrangements are compared for low rise, medium rise and high

rise buildings. Linear dynamic analysis is carried out and from the results of this study, it can be concluded that-

- In this study, the provision of shear wall proved to be the most effective structural configuration closely followed by the cross steel bracing configuration, by resulting in almost 95% decrease in terms of lateral displacements for low rises, 90% for medium rises and 95% for high rises. This correlated with previous studies deeming shear walls as the best alternative for reducing the effects of soft storey.
- As the height of the building increases, the provision of shear wall as well as cross steel bracing becomes inevitable as these techniques reduce the bending moment concentration at the open ground storey up to a great extend.
- In the present study, with increase in height of the building, the storey drift was reduced as far as 93% for low rises, 90% for medium rises and 90% for high rises by incorporation of shear wall. About 68% reduction in case of low rises, 70% for medium rises and 71% for high rises was achieved by using cross steel bracings.
- In the present work, stiffness becomes a governing factor with increase in height of the building. The stiffness of the building was increased up to 70% by using shear wall.

It can be concluded that from the above configurations, the most suited will be shear wall followed by cross steel bracings. As the height of the building increases, stability of the building becomes a major factor that can be achieved by using these structural configurations.

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